Kawaguchi Mamoru

Mike Schlaich

When talking about another culture, there is always a risk of ideas being lost in translation, and this risk is particularly acute when a foreign engineer tries to interpret the work of a colleague from Japan. I cannot hope to provide more than a glimpse of the engineer Kawaguchi Mamoru or of his impressive and overwhelmingly diverse practice. I am fortunate, however, to have a personal connection to Kawaguchi and his work and to be able to trace a specific set of lineages that span geographic and institutional boundaries. Specifically, I will describe a structure of both stems and roots, growing in multiple directions, that connects my father, Jörg Schlaich, to Kawaguchi, and I will attempt to show how engineers of the same generation can go about learning from and influencing each other, even when they are trained in different schools of thought or embedded in different engineering cultures.

I have met with Kawaguchi and his son Ken'ichi, who is a civil engineer, many times at engineering conferences and during my visits to Japan. Kawaguchi has always treated me like a friend, and each time I see him I am struck by his calm openness and generosity. In 2009 I took a group of students to Japan, and he personally welcomed them into his office and gave them a fascinating tour of his projects in Tokyo. I must also note that he is not only a great engineer, steeped in Japanese traditions of technical knowledge, but also a musician who is deeply knowledgeable about traditional Japanese culture.

Kawaguchi was born in Fukui, a little town on the west coast of Japan, in 1932. His childhood was happy but short: his family's house was destroyed by bombs in 1945, at the end of World War II. You never forget something like that. I know this from my father, to whom the same thing happened almost at the same time, but in southern Germany rather than Japan. Jörg Schlaich hardly survived the bombing of the city Heilbronn in December 1944, and the similarity of their wartime experiences is perhaps one of the reasons I started comparing the personalities of the two men. To a striking degree, their careers developed in parallel as well. Both studied structural engineering, and both were drawn to the design of lightweight structures. Both managed to successfully lead engineering offices while also working as full university professors. They met as early as 1966 during a conference of IASS, the International Association for Shell and Spatial Structures, in Leningrad, and have kept up a continuous exchange of ideas ever since. They have both received the IASS Torroja Medal (Kawaguchi in 2001, my father in 2004), and in 1997 Kawaguchi received an honorary doctorate from the University of Stuttgart, where my father was teaching.[1]

In a sense, the fact that Kawaguchi met my father so early is not surprising, since the former studied and later collaborated with Tsuboi Yoshikatsu, who was president of IASS for a time and known for cultivating strong and fruitful relationships with the international community. My father, in turn, was also actively seeking out collaborations. At the time he met Kawaguchi, he was already collaborating with the engineer Fritz Leonhardt, in Germany. Kawaguchi succeeded Tsuboi as IASS president in 1991 and continued this legacy. Indeed, his connection to my father is evidence that the world of engineering went global quite a long while ago.

Kawaguchi's first significant project was the Yoyogi National Stadium, which sheltered the swimming competitions of the 1964 Olympic Games in Tokyo. It was designed by the architect Tange Kenzō, and Tsuboi was the engineer, but Kawaguchi was very much involved in the project as a young engineer working together with his master. Looking at the front elevation, we see that the roof works like a suspension bridge and takes the familiar shape of a main cable and backstays held by two masts (fig. 7, p. 53). It is a pure catenary, a hanging structure that works in tension only. The moment we look from the side, however, we are surprised: the roof spanning from the main suspension cable toward the edges of the building does not look like a catenary. The architect wanted this shape, and it was Kawaguchi who had the idea to use bending elements, which do not have to follow the pure catenary shape, to achieve the desired form.[2] Perhaps he was thinking of Tsuboi's dictum: "A structure's beauty can be found near its rationality."[3] Kawaguchi calls this hybrid the "synthetic approach," as opposed to the European style of engineering, which he calls "pure and analytic." In the European school, one would find more tension-only or compression-only structures and fewer hybrids, with no mixing of materials. We might have opted for an all-cable solution, which would have meant leaving not only the main cable but also the roof in its natural hanging shape, but Kawaguchi is not dogmatic, and he combined cables with beams to create an altogether new shape. Nevertheless, I think most architects and engineers—regardless of style or approach—would agree that the space thus created under the roof is beautiful (fig. 9, p. 54). To me it is very much a space under a Kawaguchi structure.

This structure is quite lively, too, with a deformation of up to 2 meters during construction and large displacements due to wind and snow; hydraulic dampers had to be added to the main cable to reduce this movement. Tange and Kawaguchi made them quite visible to show how the structure works, to make it readable. This approach appeals to all of us: we like what we understand.

The first project in which Kawaguchi unquestionably took a leading role in the design was the impressively huge structure, 100 by 300 meters that covered the Festival Plaza for the Osaka Expo in 1970. The Expo structure that impressed me most, however, was the Fuji Pavilion, which Kawaguchi designed (fig. 1). As a boy I had a stamp of this small pavilion in my collection. Not only was I proud to have a stamp from Japan, but this strangely curved structure in a faraway country intrigued me. It was only much later that I came to appreciate it as one of the very first modern inflated structures. Its plan is circular, 50 meters in diameter, and the structure consists of sixteen inflated and bent tubes, each arched and connected on both ends along the perimeter of the circle. The tubes are all of equal length, so that the one in the center forms a perfect semicircle. As the other tubes are shifted away from this centerline they remain parallel to it, so they are bent more sharply and rise higher into the sky in order to retain their connection to the circle's perimeter. This approach led to an absolutely novel shape, made of novel

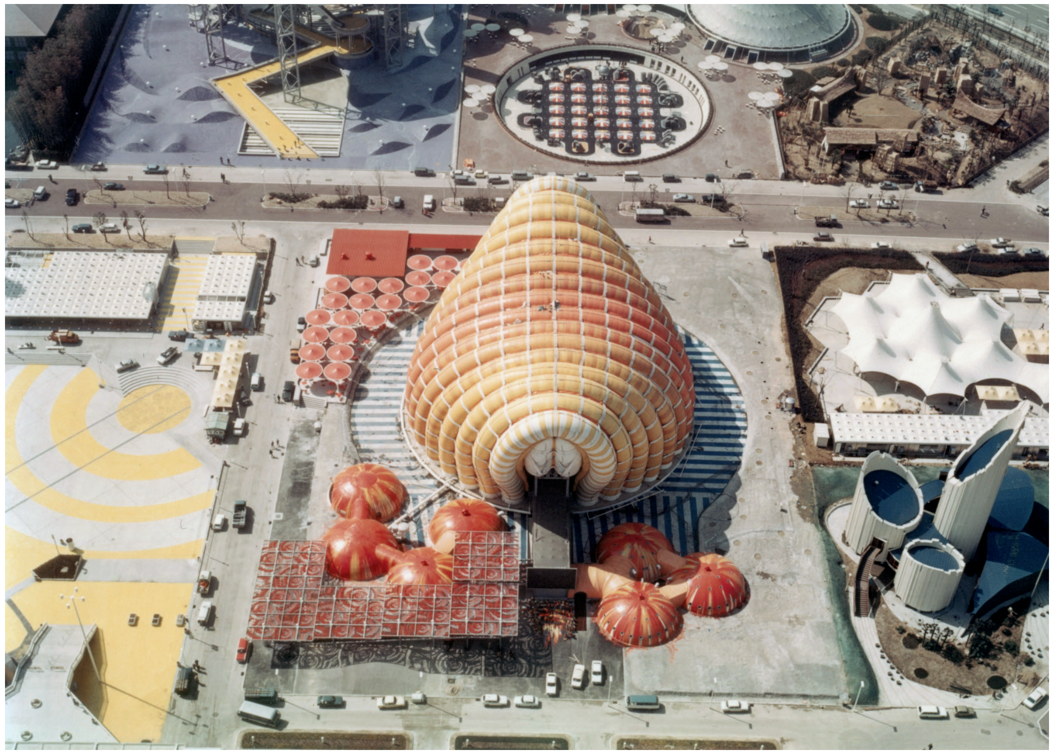


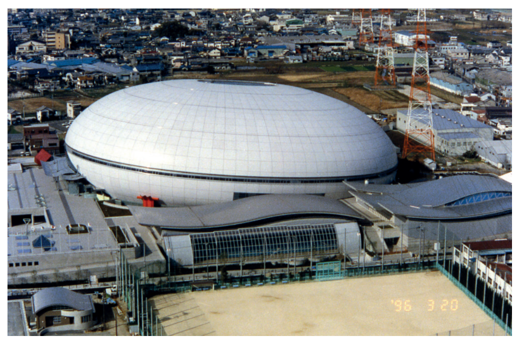
Fig. 1
Kawaguchi Mamoru
(architect and engineer).
Fuji Pavilion, Expo ’70, Osaka.
Exterior view. Completed 1970

Fig. 2
Kawaguchi Mamoru
(architect and engineer).
Fuji Pavilion, Expo ’70, Osaka.
Exterior view. Completed 1970

Fig. 3
Kawaguchi Mamoru
(architect and engineer).
Inachus Bridge, Beppu,
Ōita Prefecture.
Completed 1994

materials and with a novel structural approach (fig. 2). You have to be brave to propose a structure like this, and even braver to see it through to completion, since it is in many ways unprecedented. The tubes were very highly inflated, with a typical air pressure of up to 1,000 kilograms per square meter. In case of emergencies, such as strong winds, the pressure could be raised an additional 500 kilograms per square meter to make the structure more stable. An additional—and fascinating—safety measure was incorporated into a pond around the pavilion. An open steel pipe was immersed in this water to a depth of exactly 2.5 meters and connected to the inside of the inflated membrane tubes. When the tubes are at normal pressure, the water level in the pipe is balanced at exactly 1 meter below the surface of the pond, because 1,000 kilograms per square meter corresponds to 1 meter of water pressure. The tube pressure can be increased exactly to the allowed maximum pressure of 2,500 kilograms per square meter, but above that pressure the tube worked as a valve: any excess air would be blown out at the bottom of the pipe. The tubes could not burst. This is elegance, an effortlessly simple solution to a critical problem. This combination of daring and prudence is, to me, what makes Kawaguchi a true master of engineering.

Kawaguchi’s mastery expresses itself in another kind of combination. In Germany we do not distinguish between civil and structural engineers. You can study only to be a *Bauingenieur*, which literally translates to “building engineer.” In Japan, however, there is a very strong distinction: civil engineers do bridges, and structural engineers work with architects on buildings. The two professions hardly know each other. Kawaguchi is a remarkable exception, jumping the barriers that keep other engineers apart. His design for the Inachus footbridge (fig. 3) shows a particular sensitivity to both structure and context. Kawaguchi wanted to build a bridge with a meaningful relationship to the city of Beppu, where the bridge is located, and he chose to create a cable-supported deck using stone from Yantai, Beppu’s Chinese sister city. In addition to connecting two sides of a river, the bridge also connects two cities, its design suggesting an empathic openness. Structurally, it is no less interesting, as Kawaguchi’s hybrid approach of mixing steel and stone allowed him to produce a very slender and elegant footbridge.



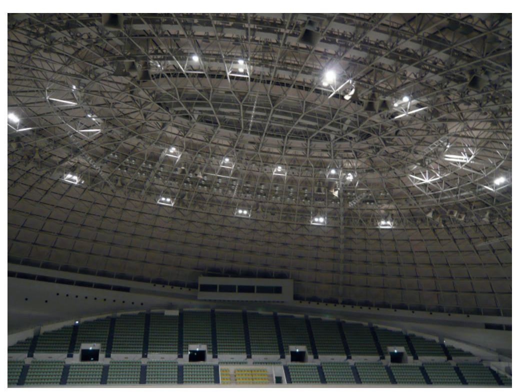


Fig. 4
Isozaki Arata (architect).
Kawaguchi Mamoru (engineer).
Palau Sant Jordi, Barcelona.
Exterior view. Completed 1990

Figs. 5–8
Kawaguchi Mamoru
(architect and engineer).
Namihaya Dome, Osaka.
Exterior view. Completed 1995

Fig. 9
Kawaguchi Mamoru (engineer).
Namihaya Dome, Osaka.
Interior view. Completed 1995

Kawaguchi also applied his talents to the problem of dome construction. Domes are double-curved surfaces, which, while being light and very efficient once finished, can be difficult and expensive to build because of the large quantities of scaffolding needed to work high above the ground. Kawaguchi addressed this problem with his idea of the Pantadome, a dome-shaped grid shell or spatial truss that can be erected easily and quickly.[4] During construction he converts the domes into a kinematic system by temporarily eliminating elements along a circle of latitude, essentially creating a line of hinges and allowing the structure to become foldable. It can be built on the ground and then lifted up by hydraulic jacks into its final position without any scaffolding. Only once it is up are the hinges fixed and the structure fully stable. And even during erection it is already stable in all directions except the vertical one (it has only one degree of freedom, in other words), which makes the lifting process a very safe one.

Palau Sant Jordi, which was built for the 1992 Olympic Games in Barcelona, is a spectacular example of a Kawaguchi Pantadome (fig. 4). The ridges on the roof indicate the location of the hinges, as the architect, Isozaki Arata, wanted to have the erection process reflected in the final structure. Remarkably, the roof was lifted with the cladding already in place. Kawaguchi has built around a dozen structures like this, some of them even inclined by as much as 5 percent from the horizontal plane. It would be difficult to lift a typical dome with such an inclination because horizontal forces could occur and cause the structure to slide sideways. The Pantadome system, however, would remain completely safe because it only has one degree of freedom in its motion. And the lifting is remarkably fast: It took only eight and a half hours to lift the huge Namihaya Dome in 1995 (figs. 5–8). The roof structure undergoes a tremendous shift during the lifting process and then remains fixed at an incline to leave a spectacular interior space (fig. 9). Pantadomes are perhaps even more impressive for being entirely invented by Kawaguchi. With this clever system, he is not continuing any lineage but simply exhibiting his own creativity.

Even when Kawaguchi is extending a lineage already established by other engineers, however, he still exhibits a remarkable degree of originality. In the case of the Festival Plaza roof for Osaka, for example, we could very well have a sense of déjà vu. We have seen similar ideas before in Konrad Wachsmann's books on modular building, and of course the famous MERO system, with versatile nodes that could produce almost any space frame, had already been patented in 1943. Structures like the lightweight roof for the "City of Tomorrow" in Berlin, constructed in 1957 with a membrane cover designed by Frei Otto, demonstrate the advantage of building with MERO nodes. But working with Tsuboi, Kawaguchi dramatically changed the scale of such structures. Increasing the diameter of a sphere tenfold means increasing the volume (and weight) by a factor of one thousand. Huge cast-steel elements were needed as nodes to create the space frame they designed for Osaka (fig. 10). During the last three decades of the twentieth century, cast steel became popular again as a building material. Was the Osaka roof the cause for the renaissance of cast steel?

In his famous book *An Engineer Imagines*, Peter Rice wrote, "We visited the space frame at Osaka, looked at it. There I saw large cast-steel nodes. . . . An idea was born."[5] Is Rice saying that his use of a large cast-steel element for the Centre Pompidou in Paris was inspired by what he saw in Osaka? Around the same time, large cast-steel nodes were used to build another major project, the cable-net roof for the 1972 Olympic Games in Munich (fig. 11). Jörg Schlaich was the engineer in charge of this design. The complex cast-steel shapes connecting the main cables carry the foundry name PHB (fig. 12), and in his account of the stadium roof, my father wrote, "As can be literally seen at the Centre Pompidou in Paris, its castings bear the same company letters PHB as the earlier castings of the Olympia roof."[6] So perhaps the Centre Pompidou should be traced back to Munich? Success has many fathers.

The Festival Plaza roof is important for another reason: its cladding is made of highly translucent and inflated membranes and most probably it is the first example of such a roof type. Individual 10 by 10 meter steel frames were prefabricated, covered with two layers of membrane, inflated and lifted into place (fig. 13).[7] These cushions were made of polyester film covered with UV-resistant coating, a material that is no longer used for construction today, although it is still deployed in the making of rescue blankets and space suits. Even with much stronger building materials, such as transparent ETFE foils, however, today we would still not attempt spans longer than 10 meters.

Fig. 10
Kawaguchi Mamoru and Tsuboi Yoshikatsu (engineers). Cast-steel node in Space Frame, Expo '70, Festival Plaza roof, Osaka.
Completed 1970

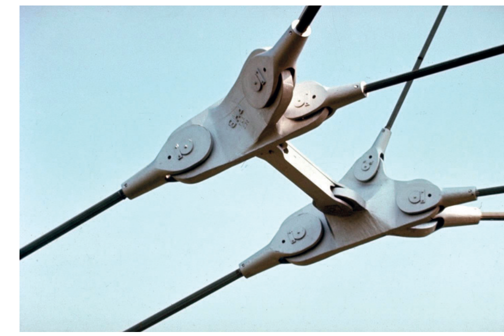


Fig. 11
Günter Behnisch and Frei Otto (architects). Jörg Schlaich (chief engineer). Roof structure, Munich Olympic Stadium.
Completed 1972

Fig. 12
Günter Behnisch and Frei Otto (architects). Jörg Schlaich (chief engineer). Cast-steel connectors, Munich Olympic Stadium.
Completed 1972

Fig. 13
Tange Kenzō (architect). Kawaguchi Mamoru and Tsuboi Yoshikatsu (engineers). Cushions on Space Frame, Expo '70, Osaka.
Completed 1970

(Following spread)
Fig. 14
Murata Yutaka (architect). Kawaguchi Mamoru (engineer). 12th World Orchids Conference Pavilions, Kanagawa Prefecture.
Exterior view. Completed 1987

Fig. 15
Murata Yutaka (architect). Kawaguchi Mamoru (engineer). 12th World Orchids Conference Pavilions, Kanagawa Prefecture.
Interior view. Completed 1987

Fig. 16
Jaime Pérez (architect). schlaich bergermann partner (engineers). Palacio Vistalegre, Madrid.
Roof. Completed 2000

Figs. 17 and 18
Jaime Pérez (architect). schlaich bergermann partner (engineers). Palacio Vistalegre, Madrid.
Exterior views. Completed 2000

Fig. 19
Planinghaus (architects). schlaich bergermann partner (engineers). Movable membrane roof for former casting house Duisburg-Nord, Duisburg.
Interior view. Completed 2003

More than 270 of these elements were combined to form the final roof. Even the cushions’ details were complex, involving tubes for inflation, which can be seen in photos, and stiffeners and belts to reinforce the film. Given how much had to be invented in such a short time (the engineer invents; the scientist discovers), the project was a most impressive success.

Kawaguchi moved on to even larger pneumatic structures in the late 1980s. For the World Orchids Conference he designed an 80-meter-diameter dome and a 100-meter-long free-form building (fig. 14). An ingenious design allowed steel cables to carry the main tension forces. Imagine a primary grid made of steel cables and a secondary 10 by 10 centimeter mesh that fills in the gaps between these main cables. A large polyester film panel was placed below these layers and then inflated: a surprisingly quick and economic and, again, most impressive solution (fig. 15).

Consciously or unconsciously, many recent roof designs were inspired by Kawaguchi’s earlier inflated structures. The movable cover of the bullfighting ring Palacio Vistalegre, in Madrid, is an inflated cushion 50 meters in diameter (fig. 16). It is supported by cables on winches and can be moved up and down 11 meters (figs. 17, 18). Although it was built in 2000 with the modern materials at our disposal—PVC-coated polyester for the top membrane and ETFE foils supported on a steel-cable net for the lower membrane—the fundamental principle of the design is familiar from Kawaguchi’s work. Another example is the open-air theater Giesshalle in Duisburg, Germany (fig. 19), which is essentially a moveable roof that runs on rails, again with inflated cushions of ETFE foil. These are some of the lineages that connect Kawaguchi to our work today.

So far I have focused primarily on Kawaguchi’s built projects, but his academic research also forms an important part of his legacy. He became Professor at Hōsei University in Tokyo in 1972 and was highly esteemed for his hands-on approach to both teaching and research. Among his many research projects, one of the most fascinating is his quest to find what he called “the shallowest possible form.”[8] From experience, Kawaguchi knew that the hemisphere works well for domes and inflated structures but also is a waste of space because of its great height in the center. A seemingly obvious alternative, the ellipsoid, would not work because it would introduce negative forces (compression in the direction of the circumference) into the membrane, causing it to wrinkle. He could prove mathematically, however, that a shape for inflatable domes can be found that has a minimum height/span relation, has a vertical tangent at the bottom, *and* does not wrinkle when inflated. Kawaguchi proved the concept by building a pavilion to which he applied another innovation: a method of inflating thin metal sheets (fig. 20).[9] These sheets were arranged along the meridian direction where high stresses occur. Since Kawaguchi had found that, for the shallowest possible form, stresses in the circumferential direction are zero, the individual sheets could be connected very easily—the joints had to be airtight but did not have to carry loads. But Kawaguchi had to solve another problem. The shallowest possible form is horizontal at the top and this, according to membrane theory, leads to infinitely high stresses there. Kawaguchi's trick was simply to leave the center part open (just as the Pantheon in Rome is open at the top) and then to cover the void with a small foil dome (fig. 21).

At practically the same time at the University of Stuttgart, experiments were being done on inflating metal membranes (figs. 22, 23). High pneumatic pressure can plastically deform thin steel sheets and yield mathematically perfect shapes. An early experiment was done with circular stainless-steel sheets that were only 0.2 millimeters thick, clamped together at the edges and inflated by compressed air. Two doctoral students were brave enough to climb the new structure to prove how strong such a super-thin dome is (fig. 24). Measured contour lines that had been marked on the surface showed that the plastic deformations of the steel sheet had yielded a very uniform geometry (fig. 25). This led to the idea of inverting the process by deflating membranes to get perfectly shaped drums that could be used as mirrors for solar energy production, and several such "dishes" were built this way (figs. 26, 27). Here we find lineages flowing back and forth: research on structural metal membranes in Japan and Germany clearly developed in dialogue.

Of course, there are also some lineages that do not connect. Another of Kawaguchi's inventions is the so-called Suspen-Dome.[10] It is a dome that works in compression, supported by struts that, in turn, are held in place by circular hoop cables and radial

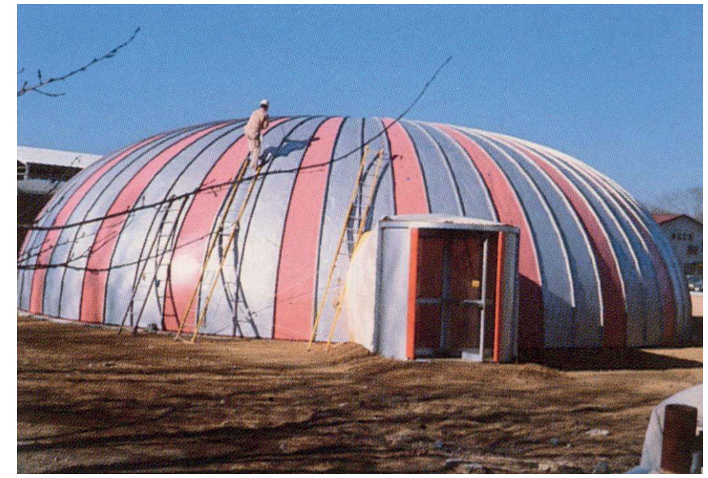


Fig. 20
Kawaguchi Mamoru (architect and engineer). Metal-membrane tension structure, Higashimatsuyama, Saitama Prefecture.
Exterior view. Completed 1979

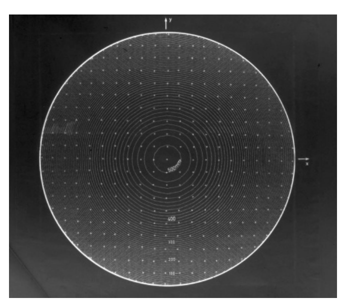
Fig. 21
Kawaguchi Mamoru (architect and engineer). Metal-membrane tension structure, Higashimatsuyama, Saitama Prefecture.
Interior view. Completed 1979

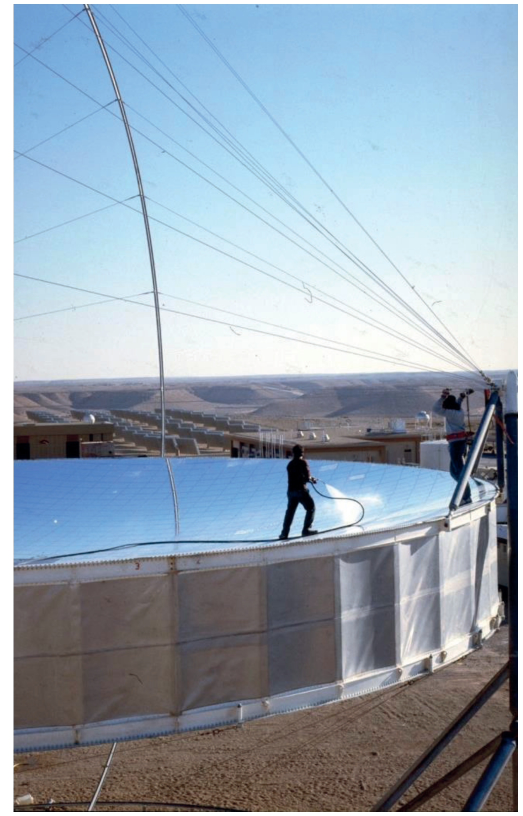
Fig. 22
Hollow cylindrical object (stainless steel, 1 mm thick) connected to high-pressure hose and water-inflated. 1974

Fig. 23
Hollow cylindrical object after inflation. 1974

Fig. 24
Jörg Schlaich and Switbert Greiner (engineers). Air-inflated test roof with upper and lower sheet metal membranes (stainless steel, 0.2 mm thick) clamped into a compression ring. Inflation creates lenticular shape. 1975

Fig. 25
Jörg Schlaich and Switbert Greiner (engineers). Photogrammetric survey of the air-inflated test roof. 1975





Figs. 26 and 27
schlaich bergermann partner (engineers).
50 kW dish/Stirling systems, Riyadh. 1985

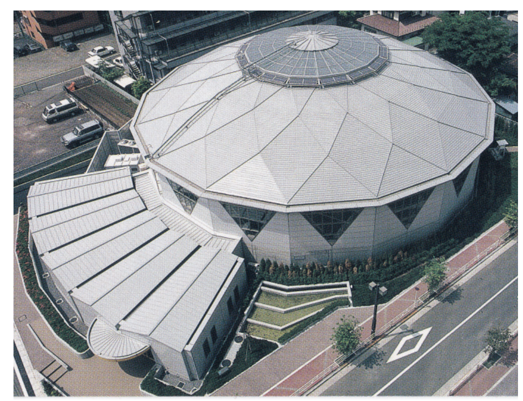
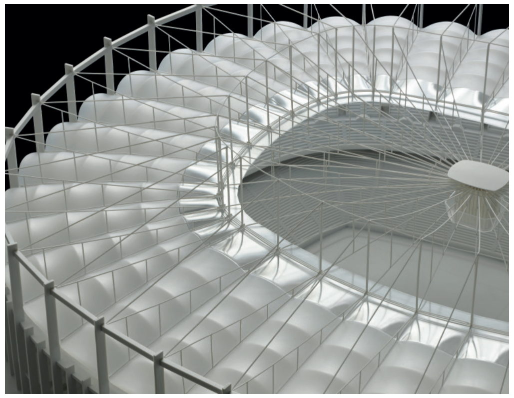


Fig. 28
Kawaguchi Mamoru (architect and engineer).
Hikarigaoka Dome, Tokyo.
Exterior view. Completed 1994

Fig. 29
Kawaguchi Mamoru (architect and engineer).
Fureai Dome, Nagano Prefecture.
Interior view. Completed 1997



Figs. 30 and 31
gmp Architekten von Gerkan, Marg und Partner (architects). schlaich bergermann partner (engineers). National Stadium, Bucharest. Completed 2011

Fig. 32
Kawaguchi Mamoru (architect and engineer). Jumbo Koinobori, Kazo. Completed 1988

cables. The compression forces of the dome, which reach the supports at the perimeter, are contained by a tension ring. The combination of support from struts and radial and hoop cables stiffen the dome to avoid buckling, allowing it to become very slender. This is another example of Kawaguchi's hybrid approach, mixing different structural components that work in bending, compression, and tension. He has built several Suspen-Domes, including the Hikarigaoka Dome in Tokyo, with a diameter of about 50 meters (fig. 28) and the Fureai Dome, the compression members of which are made of timber (fig. 29). Much to his surprise, Kawaguchi also found out that almost twenty Suspen-Domes have been built in China, although there they are called suspended domes. Typically generous, Kawaguchi did not complain that his ideas had been copied. He was, in fact, happy that his system had spread.

A structural system that looks similar to the Suspen-Dome is the Looped Cable Roof. The key difference is that here there is no dome to take compression—it is the highly tensioned upper "spokes" that carry the cladding and the live loads. All the radial cables are anchored in an outer compression ring along the perimeter of the roof. Kawaguchi does not believe in such all-tension structures. He refers to Looped Cable Roofs as cable domes, and he finds them neither elegant nor efficient. But in our office, we do design Looped Cable Roofs, and we think they are not so inefficient. Numerous stadiums, such as the National Stadium of Romania in Bucharest (figs. 30, 31), have been built using this technique and have proved to be economic and efficient.

It is impossible to summarize all of Kawaguchi's marvelous inventions and his beautiful and varied structures in a single text. But there is one project that, perhaps better than any other, captures his generous and enthusiastic spirit. A few kilometers from Tokyo, in the city of Kazo, in Saitama Prefecture, there is an annual Children's Day, on which children fly carp-shaped kites made of cotton. These are typically 3 to 5 meters in length, but in 1988, Kawaguchi was asked if he could design a carp kite that was 100 meters long. With his enthusiasm and his experience in both membrane building and aerodynamics, he succeeded. He found that cotton was actually strong enough for the task—the seams simply had to be reinforced and an aluminum ring had to be added around the carp´s mouth. As he describes it, his enormous *koinobori*, as these kites are called, was lifted by “a truck crane on a fine day of April 1988. The jumbo carp, a huge flying membrane, began to flutter in the breeze, and swam elegantly in the sky” (fig. 32).[11] Since then the carp has flown every year at Kazo on the fifth of May—a perfect tribute to its creator.

NOTES

The projects of schlaich bergermann partner treated in this paper can be found on www.sbp.de.

1. Jörg Schlaich, “Mamoru Kawaguchi: Wegbereiter des innovativen Leichtbaus in Lehre, Forschung und Praxis,” *Deutsche Bauzeitung* 140, no. 4 (April 2006): 75–79.

2. Rem Koolhaas and Hans Ulrich Obrist, eds. *Project Japan: Metabolism Talks* (Cologne: Taschen, 2011), 559.

3. Schlaich, 75.

4. Kawaguchi Mamoru and Abe Masaru, “On Some Characteristics of the Pantadome System,” in Jan B. Obrębski, ed., *Proceedings of the International IASS Symposium on Lightweight Structures in Civil Engineering, Warsaw, Poland 24–28 June, 2002* (Warsaw: Jan B. Obrębski Wydawnictwo Naukowe, 2002).

5. Peter Rice, *An Engineer Imagines* (London: Artemis, 1994), 29.

6. Jörg Schlaich, “Das Olympiadach in München,” in *25 Jahre Schlaich Bergermann und Partner* (Stuttgart: Schlaich Bergermann und Partner, 2005).

7. Kawaguchi, *Mamoru Kawaguchi: Enginyer d’estructures* (Valencia: Universitat Politècnica de València, 2009).

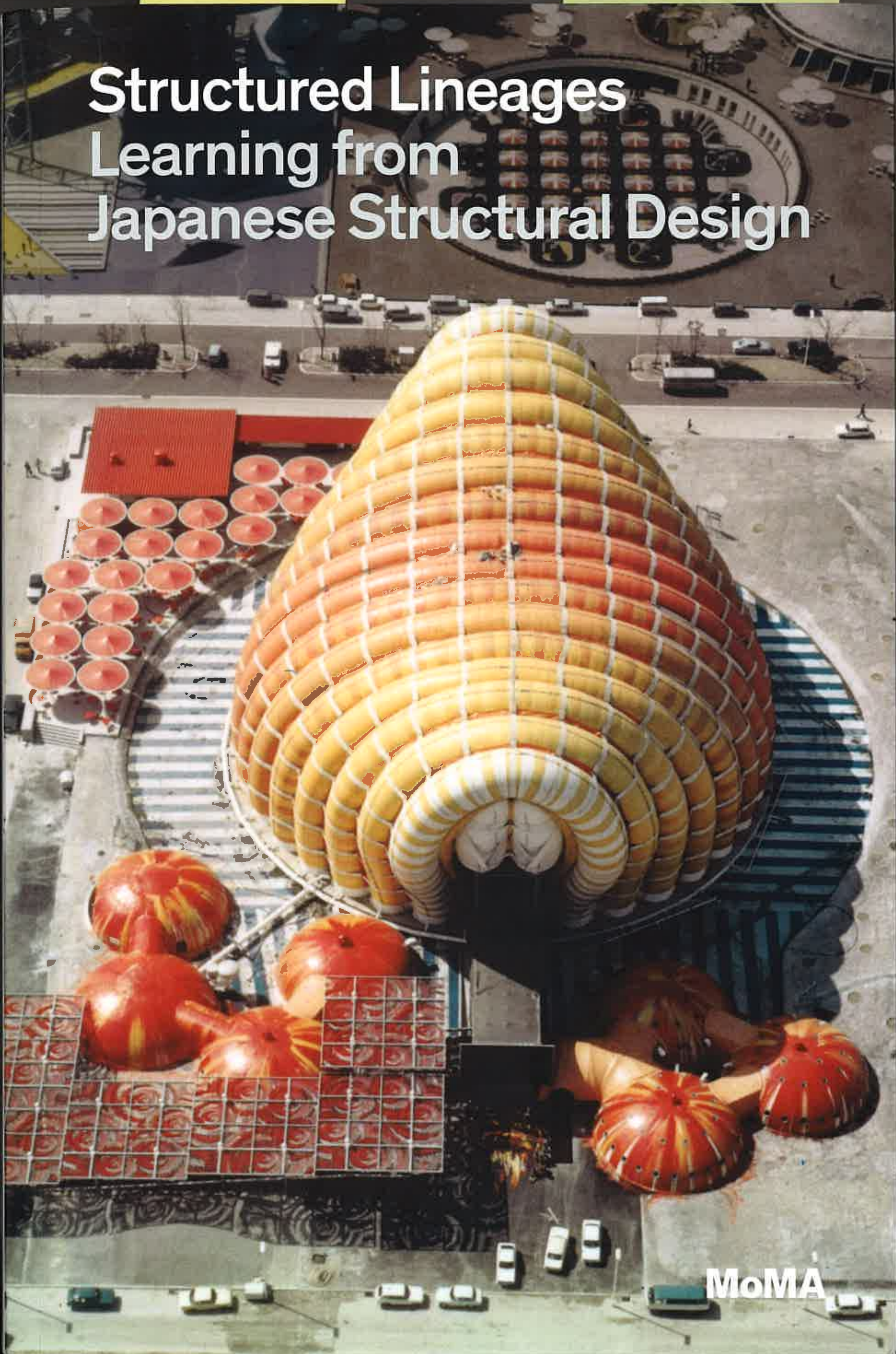
8. Kawaguchi, “The Shallowest Possible Pneumatic Forms,” *Bulletin of the IASS* 18, no. 63 (April 1977).

9. Kawaguchi, Abe, Takeyama Y., “Metal-Membrane Tension Structures,” in F. del Pozo et al., eds., *World Conference on Shell and Spatial Structures, 24–28 September 1979, Madrid, Spain* (Madrid: Laboratorio Central de Ensayo de Materiales de Construcción, 1979).

10. Kawaguchi, Abe, and Tatemichi Ikuo, “Design, Tests and Realization of ‘Suspen-Dome’ System,” *Journal of the International Association for Shell and Spatial Structures* 40, no. 131 (December 1999).

11. Kawaguchi “The Lighter, the Better?”, in IABSE and IASS, eds., *Taller, Lighter, Longer: Meeting Growing Demands with Limited Resources: IABSE-IASS 2011 London Symposium; the 35th Annual Symposium of IABSE; the 52nd Annual Symposium of IASS and Incorporating the 6th International Conference on Space Structures; London, September 20–23, 2011* (London: Hemming Group, 2011).

Structured Lineages
Learning from Japanese Structural Design



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